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The competition of memory and expectation in resolving long-distance dependencies

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Document Version

Publisher's PDF, also known as Version of record

Publication date:

2017

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Safavi, M. S. (2017). *The competition of memory and expectation in resolving long-distance dependencies: Psycholinguistic evidence from Persian complex predicates*. [Thesis fully internal (DIV), University of Groningen]. University of Groningen.

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Chapter four

Long-distance dependency resolution in Persian: evidence from eye-tracking studies on separable complex predicates

4.1. Introduction

In the sentence comprehension literature, it is well-known that processing costs increase with dependency distance (Gibson, 2000; Lewis and Vasishth, 2005); this is often referred to as locality effects. However, the expectation-based account (Hale, 2001; Levy, 2008) predicts that delaying the appearance of a verb renders it more predictable and therefore easier to process. So, we investigated whether strengthening the expectation can increase facilitation at the verb. We used Persian for this study. This language has a special construction called ‘complex predicate’, which is a separable noun-verb configurations in which the verb (the precise lexical item) is highly predictable given the noun.

While works such as Staub (2010), Vasishth and Drenhaus (2011) demonstrate that working memory constraints and predictive processing interact, it is far from clear under what conditions this happens. The experiments discussed in the current chapter investigate this interaction. In particular, we ask the following questions:

- (1) What is the effect of strong versus weak expectation strength on processing at the head?
- (2) What is the effect of the type of the intervening phrases on processing the head?

The first question is motivated by the study of Husain et al. (2014) and like them we will also use complex predicates (this time in Persian) in order to manipulate expectation strength. The notion of strong versus weak expectation, in our opinion, has the desirable property of controlling the effect of predictability such that it is experimentally measurable (through, for example, a sentence completion task).

More importantly, rather than using a continuous notion of predictability where any resulting behavioral difference might be subtle, strong versus weak expectation makes the predictability manipulation discreet, thereby possibly increasing the chance of seeing a significant effect due to expectation, if any. Although both Vasishth and Drenhaus (2011) and Levy and Keller (2013) argue that memory load is critical for having a locality or expectation effect.

The second question is motivated by the idea that if a prediction has to be actively maintained in working memory, it will take up resource and since working memory capacity is limited, processing at different levels of syntactic complexity while simultaneously maintaining a prediction may have a negative impact on the trace of the predicted chunk in memory. So,

manipulating the complexity of the intervening material provides a better manipulation to study the interaction between memory decay and expectation.

This chapter concerns the two eye-tracking studies in which we attempted to replicate the ‘results’ of the two self-paced reading studies, discussed in chapter 3.⁹ Furthermore, eye-tracking method can be very informative because it not only provides us with data about the gaze proportion and reading time but also about the regressions made while reading the sentences. Also, it is possible that self-paced reading overburdens the working-memory system in an unnatural manner (by masking the previous word once the new word appears). If this is the case, one prediction is that the eye-tracking data do not necessarily show locality effects.

It should be noted that despite a wide range of eye-tracking studies in sentence processing literature (Clifton et al., 2007; Boston et al., 2008, 2011), it is still unclear what measures reflect the effects of syntactic processing. One can generally categorize these measures to three types: (i) first-pass events; (ii) regression-related events (proportion and duration of eye gaze); and (iii) second-and later pass events (Jäger et al., 2015). In our experiments, we report the First Pass Reading Time (also, gaze duration) as well as Regression-Path Duration as the two key measures that play a critical role in answering our research questions.

4.2. Locality and expectation in Persian I: evidence from eye-tracking

In this study, we used eye-tracking method to investigate the locality and expectation effects in Persian complex predicates. To this aim, the two factors of distance (short versus long) and predictability (strong versus weak) were

⁹ This replication attempt was also motivated by the recent report of Open Science Collaboration (2015) on the replication crisis in psychology.

interposed across conditions to see whether manipulating the intervener between the parts of the complex predicate (which is considered a long distance dependency when separated) would lead to processing difficulty or facilitation at retrieving the verb.

4.2.1. Methodology

4.2.1.1. Participants

Forty participants were tested individually at the Golm Campus of University of Potsdam, Germany. There were all Iranian and native speakers of the Persian language who had been outside Iran for not more than two years. They had at least 12 years of education. None of them reported any history of neurophysiological or cognitive disorders, and all had normal or corrected-to-normal vision. Consent letters were obtained from the participants before the study and the study was conducted in accordance with Helsinki declaration.

4.2.1.2. Materials

The experimental items were the same as in the first self-paced reading experiment, except that the following four items from experiment 1 were removed: item id 5, sheka:yat kardan (complain + to do), item id 9, sahm bordan (share + to win), item id 26, pishraft kardan (progress + to do), and item id 32, hes kardan (feel + to do). The reason for removal was that the results of the sentence completion studies suggested that these light verbs had lower predictability than the other light verbs in the stimuli. It could be that this lower predictability is due to the existence of some alternative light verbs with which the nominal part can combine to make other possible complex predicates. The last two complex predicates also had a lower acceptability

rating (item 26 had 4.7, and item 32 had 3.5). As a consequence, in our eye-tracking study, we had thirty-two experimental items and sixty-four fillers. All items, including fillers are available in the appendices. A set of examples for different conditions of this experiment can be seen below.

a. Short distance + strong predictability of the head

Ali a:rezouyee bara:ye man (kard)...
 Ali wish-INDEF for 1.S (do-PST) ...
 ‘Ali (made) a wish for me...’

b. Long distance + strong predictability of the head

Ali a:rezouyee ke besya:r doost-da:asht-am
 Ali wish-INDEF that a lot like-1.S-PST
bara:ye man (kard)...
 for 1.S (do-PST) ...
 ‘Ali (made) a wish for me that I liked a lot. . .’

c. Short distance + weak predictability of the head

Ali shokola:ti bara:ye man (xarid)...
 Ali chocolate-INDEF for 1.S (buy-PST) ...
 ‘Ali (bought) a chocolate for me...’

d. Long distance + weak predictability of the head

Ali shokola:ti ke besya:r doost-da:sht-am
 Ali chocolate-INDEF that a lot like-1.S-PST
bara:ye man (xarid)...
 for 1.S (buy-PST) ...
 ‘Ali (bought) a chocolate for me that I liked a lot...’

4.2.1.3. Procedure

An eye-tracking study was prepared using Experiment-Builder software, and participants’ eye-movements were recorded using an EyeLink 1000 tracker, with a connection to a PC. Before the experiment started, the participants were instructed to read the sentences silently at a normal pace and had a practice block consisting of five sentences. After answering the comprehension

questions of the practice block, they were provided with feedback indicating whether or not the answer was correct. For example, for a sentence like *I ate what my mother had cooked*, the comprehension-check true/false question was *I ate what my wife had cooked*(in Persian).

A 21-inch monitor was placed 60 centimeters from the participants' eyes. In order to reduce head movements, the participants were asked to use the chin-rest. They viewed the sentences with both eyes, but only the right eye was recorded. The items were presented in one line (the whole sentence appeared at once) and in 18 points Persian Arial font (from right to left). First, they had to fixate on a dot at the right edge of the screen so that the sentence appeared. After they finished reading, they had to fixate on the dot in the bottom left corner of the screen; once they fixated on the dot, the comprehension question was presented. Unlike with the practice items, they were not provided with any feedback. Calibration was performed at the beginning of the experiment, after their 5-minute break (which occurred after they had were halfway through the experiment), and whenever it was necessary.

4.2.1.4. Statistical analysis

Raw gaze duration data were obtained using the Data Viewer software. These data were then processed to get different eye-tracking measures using the 'em2 package' (Logac̣ev and Vasishth, 2013). Bayesian linear mixed models were used for the analysis. All analyses were carried out using log-transformed data. Zero ms reading times were removed before carrying out the analysis.

4.2.2. Results

4.2.2.1. Response accuracy

On average, participants answered 92 percent of the target comprehension questions correctly. Mean accuracy by condition was 91 percent for condition a, 91 percent for condition b, 95 percent for condition c, and 89 percent for condition d. We found no effects of distance and predictability, and no interaction.

4.2.2.2. Eye-tracking measures

The critical region was the verb, as in the self-paced reading studies discussed in chapter 3. The same sum contrast coding was also used here. We present results for first-pass reading time and regression path duration.

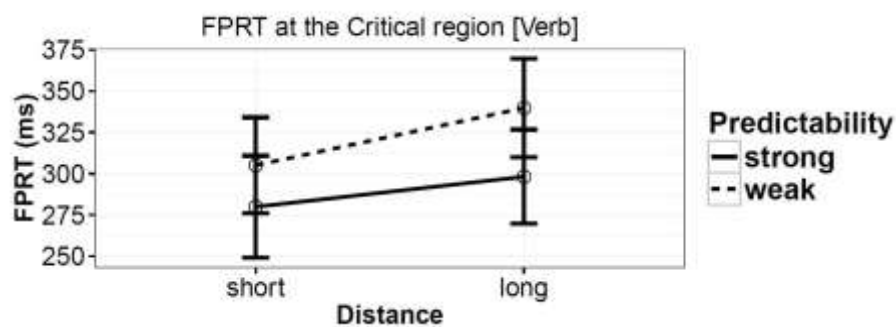


Figure 4.1. First-pass reading time (FPRT) at the critical verb in the first eye-tracking experiment looking for the effects of distance and predictability. Error bars show 95% confidence intervals.

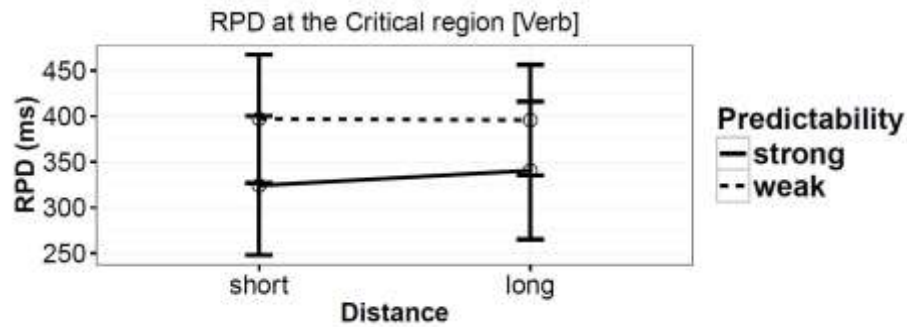


Figure 4.2. Regression Path Duration (RPD) at the critical verb in the first eye-tracking experiment looking for the effects of distance and predictability. Error bars show 95% confidence intervals.

As indicated in **Figure 4.1** and **Figure 4.2**, the effect of predictability, seen in the self-paced reading experiments, is also present in first-pass reading time ($t=-3.08$) and in regression path duration ($t=-3.21$); while the strong-predictability conditions had shorter reading times. Also, as in the studies in previous chapter, there was an effect of distance in first pass reading time ($t=2.67$); the long-distance conditions have longer reading times. **Table 4.1** shows the details of the analyses.

Table 4.1. Coefficients, standard errors, and t-values for the main effects and interactions in first-pass reading time (FPRT) and regression path duration (RPD) in the first eye-tracking experiments looking for the effects of distance and predictability

ET 1 measures	Comparison	Coef	SE	t value
Log FPRT	Intercept	5.62	0.03	175.88
	Distance	0.05	0.02	2.67
	Predictability	-0.053	0.02	-3.08
	Distance × Predictability	0.01	0.01	0.79
Log RPD	Intercept	5.73	0.04	128.98
	Distance	0.04	0.02	1.47
	Predictability	-0.08	0.02	-3.21
	Distance × Predictability	0.004	0.02	0.26

In the Bayesian analysis, sum contrast coding was used as in the self-paced reading experiments. We present results for first-pass reading time and regression path duration.

The effect of predictability, seen in the self-paced reading studies, is also present in first-pass reading time and regression path duration; the strong-predictability conditions had shorter reading times. There was also an effect of distance in first-pass reading time but only a weak effect in regression path duration; the long-distance conditions had longer reading times. **Table 4.2** shows the details of the analyses.

Table 4.2. Means, 95% uncertainty intervals, and $P(b < 0)$, the probability of the estimate being less than 0, in the first-pass reading time (FPRT) and regression path duration (RPD) for the first eye-tracking experiment looking for the effects of distance and predictability

ET measure	Comparison	Mean	Lower	Upper	$P(b < 0)$
FPRT	Intercept	5.623	5.5627	5.6833	0
	Distance	0.0504	0.0123	0.0868	0.0062
	Predictability	-0.0522	-0.0844	-0.0189	0.9968
	Distance × Predictability	-0.01	-0.039	0.0196	0.7455
RPD	Intercept	5.7286	5.646	5.8105	0
	Distance	0.0331	-0.0139	0.0814	0.074
	Predictability	-0.0754	-0.1248	-0.0265	0.9992
	Distance × Predictability	-0.0032	-0.0374	0.0316	0.5742

4.2.3. Discussion

In this eye-tracking study, we replicated the locality effects found in the reading time of self-paced reading studies. These locality effect appeared in weak-predictability conditions, which is similar to the result in the first self-paced reading as discussed in chapter 3. A main effect of predictability was found in first-pass reading time and regression path duration, replicating the effect in self-paced reading 1. Since we failed to find an interaction between predictability and distance, we cannot conclude, as Husain et al. (2014) did, that expectation effects can cancel out locality effects.

The locality effects are consistent with working memory accounts (Gibson, 2000; Lewis and Vasishth, 2005) and inconsistent with the distance-based predictions of the expectation account (Levy, 2008). As in the self-paced reading experiments, we have evidence consistent with a version of the expectation account that predicts that strong predictability conditions are read faster than the weak predictability conditions. In sum, the main result of the first eye-tracking study is that we have replicated the locality effect and the facilitation due to strong predictability with a different methodology.

4.3. Locality and expectation in Persian II: evidence from eye-tracking

In the following sections, the second eye-tracking study will be described which aims at investigating locality or expectation effects in separable Persian complex predicates by manipulating the conditions with the two factors of distance and predictability similar to the second self-paced reading study discussed in chapter 3. We will explain the design and experimental items in the materials section in details. The main motivation for conducting such a comparative study was that self-paced reading may add higher load to working memory as the stimulus is shown word by word which is in contrary to the

way our brain is used to. So, eye-tracking can be a more informative method for the natural process of reading, while providing more information about the proportion of eye gaze and regressions. As a result, we might not see the locality effects found in the similar self-paced reading study.

4.3.1. Methodology

4.3.1.1. Participants

Forty individuals (different from the previous group) participated in the study which was conducted at the Golm Campus, University of Potsdam, Germany. They were all Iranian, native speakers of Persian, with no report of physiological or mental disorders, with minimum 12 years of education, and normal or corrected-to-normal eye-sight. The guidelines of the study were in accordance with the declaration of Helsinki and the participants signed consent letter before they actually started the experiment.

4.3.1.2. Materials

The experimental items were the same as in the second self-paced reading experiment, but with 32 items (see the explanation for the first eye-tracking experiment above regarding the four items that were removed). The experimental items were complemented with 64 filler sentences with varying syntactic structures. A set of examples for the four conditions can be seen below.

a. Short distance + strong predictability of the head

Ali a:rezouyee bara:ye man (kard)...

Ali wish-INDEF for 1.S (do-PST)...

‘Ali (made) a wish for me...’

b. Long distance + strong predictability of the head

Ali a:rezouyee bara:ye doost-e xa:har-e man (kard)...
Ali wish-INDEF for friend-EZ sister-EZ 1.S (do-PST)...
'Ali (made) a wish for my sister's friend...'

c. Short distance + weak predictability of the head

Ali shokola:ti bara:ye man (xarid)...
Ali chocolate-INDEF for 1.S (buy-PST)...
'Ali (bought) a chocolate for me...'

d. Long distance + weak predictability of the head

Ali shokola:ti bara:ye doost-e xa:har-e
Ali chocolate-INDEF for friend-EZ sister-EZ
man (xarid)...
1.S (buy-PST)...
'Ali (bought) a chocolate for my sister's friend...'

4.3.1.3. Procedure

The procedure was the same as the first eye-tracking experiment.

4.3.1.4. Statistical analysis

The statistical analysis was the same as the first eye-tracking experiment.

4.3.2. Results

4.3.2.1. Response accuracy

On average, participants answered 90 percent of comprehension questions correctly. They had 94 percent response accuracy for condition a, 88 percent for condition b, 94 percent for condition c, and 86 percent for condition d. None of the factors had an effect on accuracy.

4.3.2.2. Eye-tracking measures

Unlike the first eye-tracking study, in the second experiment, we found effects of distance ($t=2.46$ and $t=3.63$) and predictability ($t=05.10$ and $t=4.76$) in both measures of first-pass reading time and regression path duration (see **Figure 4.3** and **Figure 4.4**). In other words, the long conditions (b and d) were read slower than the short conditions (a and c), and the weak predictability conditions (c and d) were read slower than the strong predictability conditions (a and b). None of the measures showed an interaction between predictability and distance (see **Table 4.3**).

Table 4.3. Coefficients, standard errors, and t-values for the main effects and interactions in the second eye-tracking experiment looking for the effects of distance and predictability

ET measures	Comparison	Coef	SE	t value
Log FPRT	Intercept	5.67	0.04	147.60
	Distance	0.06	0.02	2.46
	Predictability	-0.11	0.02	-5.10
	Distance \times Predictability	-0.01	0.02	-0.30
Log RPD	Intercept	5.79	0.05	125.45
	Distance	0.08	0.02	3.63
	Predictability	-0.11	0.02	-4.76
	Distance \times Predictability	0.01	0.02	0.43

Based on the Bayesian analysis, we also found effects of distance and predictability in both the measures (see **Table 4.4**). In other words, in the two measures reported, the long conditions (b and d) were read slower than the short conditions (a and c), and the weak predictability conditions (c and d) were read slower than the strong predictability conditions (a and b). None of the measures showed any interaction between predictability and distance.

Therefore, the results of the Bayesian modeling are the same the linear mixed model explained above.

Table 4.4. Means, 95% uncertainty intervals, and $P(b < 0)$, the probability of the estimate being less than 0, in the reading time analysis for the second eye-tracking experiment looking for the effects of distance and predictability

ET measure	Comparison	Mean	Lower	Upper	$P(b < 0)$
FPRT	Intercept	5.6731	5.6015	5.7448	0
	Distance	0.0557	0.0099	0.1013	0.0082
	Predictability	-0.1079	-0.1512	-0.0638	1
	Distance x Predictability	-0.0046	-0.0397	0.0315	0.6088
RPD	Intercept	5.7958	5.7113	5.8799	0
	Distance	0.0767	0.0316	0.1225	5e-04
	Predictability	-0.1108	-0.1588	-0.0626	1
	Distance x Predictability	0.0089	-0.0381	0.0547	0.3452

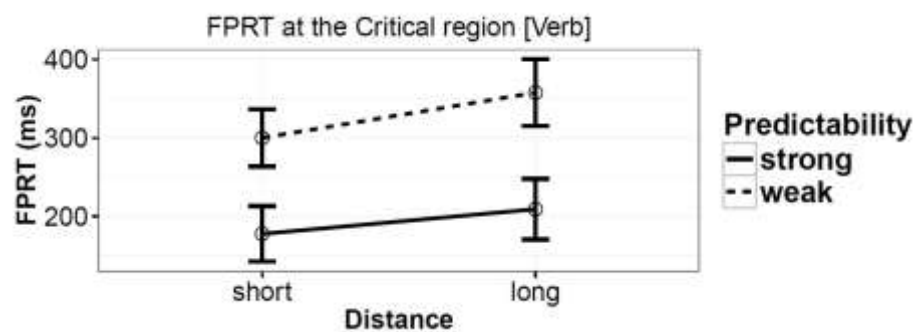


Figure 4.3. First-pass reading time at the critical verb in the second eye-tracking experiment looking for the effects of distance and predictability. Error bars show 95% confidence intervals.

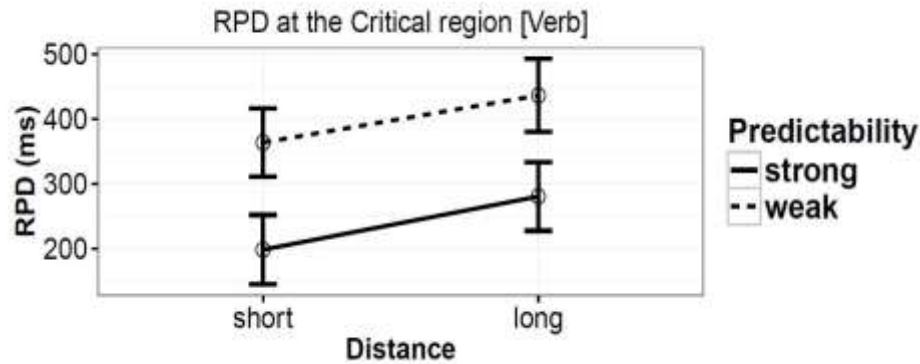


Figure 4.4. Regression path duration at the critical verb in the second eye-tracking experiment looking for the effects of distance and predictability. Error bars show 95% confidence intervals.

4.3.3. Discussion

The second eye-tracking experiment replicated the results of the second self-paced reading experiment: there was a main effect of distance and a main effect of predictability, with no evidence for an interaction. The effects in first-pass reading time and regression path duration showed essentially the same patterns as in the first eye-tracking study. However, the locality effects were even stronger, in the same way that the second self-paced reading study showed stronger locality effects. Also, these effects are equally strong in both the strong and weak predictability conditions, confirms our finding in the second self-paced reading study.

Overall, regarding the distance manipulation, the results are consistent with memory-based accounts, and inconsistent with the expectation account. The main effect of predictability is consistent with the expectation account, as discussed earlier. In the second eye-tracking study, we do not see any evidence consistent with the Husain et al. (2014) proposal; if anything, the locality effect is stronger in the strong-predictability conditions.

4.4. General discussion

In these two eye-tracking studies, which had similar experimental design and items to the self-paced reading studies presented in the chapter 3, we tried to have a more in-depth view of how a long-distance dependency such as Persian separable complex predicates can be resolved and to what extent our memory and expectation can affect this process. As our sentences were presented word-by-word in the self-paced reading experiment, we think that there might have been an unnecessary load on the participants' working memory that caused more difficulty in retrieving the light verb as a function of increased distance from its dependent noun, i.e., locality effects. Therefore, we used eye-tracking as a method that represents a more natural way of reading (by showing the sentence at once) and gives us more detailed information about the eye gaze. If the locality effects seen in self-paced reading experiments were due to the memory overload, we would expect a different result in eye-tracking studies. However, the results were interestingly quite similar to the previous ones.

Our results were in line with the key prediction of memory-based accounts, specifically Dependency Locality Theory (Gibson, 2000), in which a slow-down was expected due to increased distance between the parts of the complex predicate. There was a significant effect of distance in the first-pass reading time of the first eye-tracking study in which both relative clause and prepositional phrase formed the intervener of the long conditions. This effect was the same in the second eye-tracking study in both first-pass reading time and regression path duration. So, in both experiment, the effects of locality in favor of memory-based account were clearly seen. This finding was in contrary to the first prediction of the expectation-based account (Levy, 2008) in which a speed-up is predicted as a function of increased distance. However, the memory-based accounts do not take into account the level of predictability of the head which is a main factor considered in expectation-based accounts.

In this respect, a prediction of the expectation-based account was upheld as we consistently found a main effect of predictability in both first-pass reading time and regression path duration measure of both eye-tracking studies. In other words, the strong predictability conditions (i.e., complex predicates) were read faster than weak predictability conditions (i.e., simple predicates) across all conditions. As we found no effect of interaction between distance and predictability, we have no compelling evidence that high expectations (of the verb) can cancel the locality effects, as argued by Husain and colleagues (2016). Also, Levy's (2008) prediction that verb-final languages exhibit the patterns of memory-based accounts was not validated in our Persian data.